

Design of a
Hydro-Electric Plant

L. B. Jones
M. V. Stagg

1907

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DESIGN
OF A HYDRO-ELECTRIC PLANT.
A THESIS

PRESENTED BY

L.B. JONES and M.V. STAGG

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

1907

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John E. Snow
Acting Director Elect. Eng. Dept.

- DESIGN OF A HYDROELECTRIC PLANT -

Due to the fact that data on available water supply for any given locality could not be obtained in the time allotted, various assumptions were made in regard to location, head, quantity of water, and distribution of load.

It was assumed that the plant is to be located on the bank of a mountain stream at the foot of the mountain. The effective head was taken to be 500 feet obtained through a pipe line 3000 feet long running down the side of the mountain. At the head of the pipe line a reservoir is located formed by damming a canon, which gives capacity sufficient to supply wheels operating under full load for one week in case the stream should become low. The water from the wheels discharges into the tail-races which empty into the stream at a sufficient elevation to prevent the river from backing up into the wheels.

The output of 4000K.W. is divided among three sub-stations as shown in sketch. Sub-station No. 1 is located in a town with lighting as the principal load. Step-down transformers are provided to supply this load, which constitute the principal equipment of the plant. The current required to operate the railway is supplied through frequency changers located in sub-stations Nos. 1 & 2, which change the frequency from 60 cycles to 25 cycles. The frequency changer is supplied with 1100 volt current

from step-down transformers and gives the same voltage at the distributing end. The balance of the output of station No. 2 is used to operate motors in a small mine located in the vicinity. Sub-station No. 3 supplies power for motors located in a group of mines nearby. Step-down transformers are located in this station and constitute the main part of the equipment.

The arrangement of the transmission system is such that it will permit of continuous operation should a breakdown occur in any one part. The transmission line to sub-station No. 1 consists of two duplicate three-phase lines which ordinarily operate in parallel but either one can be used to carry the entire current in case of an emergency. The remainder of the system consists of single three-phase lines. The sub-station equipment of switches will permit of receiving and transmitting current in either direction.

The generator room is 84' x 35', the walls being of brick and one foot thick. A gravel roof covers the entire plant. It is supported by a four foot steel truss and drains to the center where the water is taken off by a down spout through the interior of the plant. The floor is made of cement except in the space surrounding the machinery. In these places an iron grating forms the floor which can be easily removed for inspection or repair of apparatus. The crane is electrically operated and runs on a track laid on two beams supported by steel

columns built in the walls. Its capacity is 30 tons. Two large doors in the end of the plant are provided for placing the machinery.

It was found from data published by The Pelton Water Wheel Co. that 9,220 cu. ft. of water per minute would be required for the maximum load on the six wheels. From a consideration of the allowable velocity in the pipe to keep the loss due to friction within a fair value it was decided to make the diameter of the pipe in the supply line 54". For this value the velocity of the water is 9.67 ft. per second with a loss in head of .766 ft. per 100 ft. length of pipe. From a consideration of other hydroelectric plants this is an average value.

The pipe line approaches the power house from the south and enters the end of a header 60 inches in diameter and 5/8 inch thick running along the west side of the generator room, supported on a suitable concrete foundation.

A battery of four safety relief valves is located at the extreme north end of the header and so arranged that they discharge into a single pipe leading into the stream below the tail-races. The relief valves are placed in a man-hole affording easy access to valves in case repairs or adjustments become necessary.

Taps for the generator wheels are 24 inches in diameter where they come off the header and taper to 20 inches at the gate valve which is also 20 inches in diam-

eter. Taps for the exciter wheels are 10 inches in diameter and run in a straight line to the wheels.

The gate valves for the generator wheels are both electrically and hand operated. A small motor mounted upon and geared to the valve permits of the valve being opened or closed from the switch board. The motor is geared to such a ratio that it requires 20 minutes to open or close the gate valve completely, thus eliminating any possibility of bursting the piping system due to water-hammer. There is a small pipe provided for filling the nozzle before opening the gate valve and the valve for this pipe is operated from the floor directly above the gate valve.

A ball and socket, deflecting type nozzle fitted with a needle valve is coupled directly to the gate valve. The needle valve is controlled by a hand wheel conveniently located near the gate valve control. The nozzle is counter-balanced by a hydraulic cylinder receiving pressure from the header and mechanically connected to the governor by a system of rods and levers.

It can be seen that by means of this system of control a wheel may be started from the switch board and the station operator can, by use of the needle valve, regulate the flow of water to correspond with the maximum load for any hour of the day and the governor will then, thru the deflecting nozzle, maintain the speed constant between this maximum and zero load.

The control of the exciter wheels is accomplished by means of simple hand operated gate valves.

The tail races were designed to eliminate any possibility of the discharge water interfering with the efficient operation of the wheel or nozzle. The discharge, located on the east side, is sufficiently high above the stream to avoid any trouble due to water backing up in the tail race in case of high water. The location of the pitch line of the wheel and center line of the nozzle with respect to the tail race is such that the direct force of the jet cannot strike the top or sides of the tail race, thus eliminating the excessive wear on the concrete.

All the wheels in the plant are of Pelton make and are mounted on the same shaft as the generators in a manner commonly known as "overhung construction".

The generator wheels, four in number, are 8-1/2 feet in diameter and develop 1,500 horse power each running at 200 revolutions per minute. This diameter of wheel was determined from the fact that the peripheral velocity of the pitch line of the buckets must be one half the velocity of the jet, for maximum efficiency while the R.P.M. is determined by the generators which were of standard type with a fixed speed of 200 revolutions per minute.

The two exciter wheels, are over hung as stated above and are three feet in diameter, developing 188 horse power each running at 571 revolutions per minute. The water from the exciter wheels discharges into one com-

mon tail race.

Sheet steel casings are provided for each wheel which can be easily unbolted at the floor line and lifted off for inspection of the wheels. The shaft passes thru one side, thus making only one gland necessary and decreasing the possibility of leakage.

Four alternators are direct- connected to over hung Pelton wheels, there being one wheel for each alternator. The alternators are manufactured by the General Electric Company and are known as type ATB with normal output of 1000 K.W. They are designed to give three phase current at 2300 volts and 60 cycles at 200 r.p.m., and to stand a 25% overload for two hours without serious heating.

The excitation current for these alternators is furnished by two 125 volt exciters with a capacity of 125 K.W. each. They are direct connected to 36 inch Pelton wheels designed to run at 600 r.p.m. The exciters are of sufficient capacity to carry the entire D.C. load of the plant, including the lights, crane motors, control switches, etc. It was not deemed necessary to use a storage battery because each of the exciters is driven by separate wheels fed through individual pipes, thus making a break down of both exciters unlikely.

The switch board is located on a gallery in one end of the plant, thirteen feet above the generator room floor level. This gallery runs the entire width of the generator room and is supported by two cast iron columns.

not all cases

Some cases involve the use of force or violence, and in such cases the law is clear. In other cases, the law is less certain, and the courts have had to decide what constitutes a breach of the law. In some cases, the law is clear, but the facts are difficult to establish. In other cases, the facts are clear, but the law is difficult to apply.

The law is a complex system, and it is not always easy to understand. However, it is important to know the law, and to know when you are breaking it. The law is not just a set of rules, it is a system of justice. It is a system that is designed to protect the rights of the people, and to ensure that everyone is treated fairly. The law is a system that is designed to be fair, and to be just. It is a system that is designed to be a guide for the people, and to be a source of comfort and security.

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A flight of stairs lead to it from the vicinity of the generators, thus making it quickly accesible from the governors and gate valves. The switch board is constructed of white marble and is made up of seven panels consisting of one exciter, four generator, and three line panels, all of which are seven feet high. The exciter panel is three feet wide while the others are two feet six inches, thus making the total length eighteen feet. The board is so placed that a space four feet wide is left for operating purposes.

The exçiter panel carries an ammeter for each exciter while the voltage is obtained on a single voltmeter by means of a plug switch which shifts the connections from one exciter to the other. The exciters are arranged for parallel operation having the equalizer connected to the center terminal of the three pole switch, thus connecting the equalizer at the same instant as the line terminals. The rheostats are placed under the floor of the gallery and connected by means of two small shafts and bevel gears to the hand wheels on the board. On the lower portion of the panels are the exçiter field switches and switches for lighting, crane operation, and for tying the operating busses to the exciter busses. Current is brought to the exciter panel through cables laid in the three-and-a-half-inch tile while the field wires are laid in three-quarter-inch conduit.

The generator panels, four in number, are placed

in the central portion of the board. On the end panels an ammeter for each phase and one for the generator field are provided. The voltmeter is shifted from one phase to another by means of a plug selector switch. Bristol recording voltmeters and wattmeters give a graphical record of the output, voltage, and power from that particular unit. Switches are provided for oil switch control, each having a red lamp above and a green lamp below to indicate the position of the oil switch. A two-pole double-throw switch operates a series motor on the gate valve, the direction of the motor being reversed by throwing the switch to the other two terminals. A similar arrangement provides an electrical control of the governor, thus making it possible to bring a generator up to voltage, synchronize it with the other generators on the busses, and connect it to these busses without leaving the board. The field of each generator has a switch which short circuits the field through a resistance at the instant the circuit is broken, thus doing away with destructive arcing and danger to insulation. A single-^{pole}~~throw~~ double-throw knife switch cuts the resistance in or out of the fields by means of the electrically operated rheostats placed under the floor of the gallery.

The line panels carry three ammeters and an oil switch control switch with its indicating lamps. A plug selector switch changes the voltmeter connections from one potential transformer to another on the opposite side

of the sectionalizing switch, thus making it possible to read the voltage on either section while they are operating separately. A frequency meter and a power factor meter are mounted on a bracket at the end of the board. The highest alternating current potential on the switch board is 115 volts, derived from the potential transformers, and the highest direct current potential is 125 volts, derived from the exciters.

With reference to the theoretical wiring diagram it can be seen that the generators are tied directly to the single phase transformers without the intervention of switches of any kind. This does away with the 2300 volt busses and since there are no low potential feeders the simplification of wiring was deemed advisable. All the generator instruments are energized through current and potential transformers placed on the low tension side of the power transformers. A high tension potential transformer is connected to the 30,000 volt busses and its low tension side is connected to the synchroscope and synchronizing busses. By means of the synchronizing plugs a generator may be synchronized with the buss bars and the oil switch closed at the proper instant by means of the oil control switch. The indicator lamps are energized from the operating buss.

Three ammeters are connected to two current transformers in such a way that they read the current in their respective phases. As mentioned before, a plug selector

switch connects the voltmeter between any of the three phases. A polyphase integrating wattmeter is connected to two current and two potential transformers so as to measure the true output of each generator on balanced or unbalanced load.

The high potential side of the transformers is connected directly to a G.E. type H oil switch. On the bus bar side of these oil switches disconnecting switches are provided so that, in case of repairs to the transformers, generator, or oil switch of a unit are necessary, they can be made with safety. Opening the disconnecting switches entirely disconnects the entire unit from the bus bars. The wiring for the four units is identical.

A sectionalizing switch provides means of dividing the plant into two equal divisions should trouble occur in one half or should it become desirable to operate one feeder separately. When the operator wishes to close the sectionalizing switch, the two portions of the busses must be first synchronized. This can be done by means of the generator synchronizing apparatus as in the case of synchronizing a generator.

Since all the power goes directly to sub-stations, no power measuring instruments have been placed in the transmission circuits, it being assumed that each sub-station measures its energy input by means of integrating wattmeters. Three ammeters are connected as in the generator wiring which indicate the load on the separate phases. On each feeder, disconnecting switches are placed

at the top of the lightning arrester near the entry, which, when open, entirely disconnect the transmission line at the entry.

The switch house, consisting of three floors, is separated from the generator room by a wall provided with the necessary doors for access to the various compartments. The construction is of steel and concrete throughout, making the whole as nearly fire proof as possible. A stairway is provided at the south end and an opening beside the stairway permits of lifting apparatus from the ground floor to the floors above.

The transformers are located on the first floor and a separate compartment is allotted for each bank. Each compartment is 10 ft. wide, 16 ft. 6 in. long, and 12 ft. 6 in. high, and is fitted with curtain steel doors 12 ft. wide, allowing ample room for removing the transformers which are mounted on trucks and provided with a track running out into the generator room far enough to permit the transformers to be handled by the crane. The floors are given a slight slope toward the east wall and a drain provided.

The 2300 volt leads from the generators are run into the transformer compartments and up onto a rack of copper rods supported from the ceilings with suitable insulators. From these racks the primary coils are connected delta by means of short leads.

The high tension leads come out thru the opposite side of the transformers and run directly to insulators on the east wall where the delta connection is made. Each wire has at least one foot clearance on all sides. In the center of the mesh for the delta connection a hole is cut into the wall and the leads from the bank of transformers pass thru wall type insulators supported on a slab of slate set into the window frame and into the barriers on the opposite side of the wall. These barriers continue up to the ceiling of the second floor, passing thru the first floor where entrance to the oil switches, located on the third floor is made. Coming out of the oil switches the leads and barriers continue across the ceiling of the second floor and downward to the bus bar compartment located on the floor and against the west wall.

The line leads come off the bus bars in the same manner and follow the same course thru the house down to one foot below the ceiling of the first floor back of the transformer compartments with the exception that disconnecting switches are placed between the bus bars and the oil switches inside the barriers.

The potential transformers are supported on the wall of the transformer compartment and leads brought down from the line wires. The line wires themselves, pass through series transformers on the east wall of the house and from there directly upwards between barriers spaced two feet apart, thru the reactance coil located in the

same barriers, and on to a disconnecting switch. The lower point of this switch is also connected to the lightning arrester supported on the barriers. The top point of the switch is connected to the line passing thru the wall of the building in a tile tube two feet in diameter, protected from rain and sleet by a suitable shelter, and downward to a cross-arm firmly supported on the side of the building.

The lightning arrester compartment is separated from the other compartments by a concrete wall and is continuous from the second floor.

The sectionalizing switch is located on the third floor directly above the bus bar compartment on the second floor and the busses are carried upwards thru suitable barriers.

The oil switches used are the type H and are made by the General Electric Company. The lightning arresters, choke coil, potential and current transformers, power transformers, and disconnecting switches are made by the same company. The insulators are made by the Locke Insulator Co. and are tested at 45,000 volts.

The bus bar compartment and barriers are made of concrete.

The generator room is lighted by five arc lamps and by clusters of incandescent lamps which are placed along the walls. Five large windows are placed along the

west wall, affording ample illumination in the day time. Incandescent drop lamps are placed wherever required.

The switch house is illuminated entirely by incandescent lamps.

From the above detailed description it can be seen that the plant is as nearly fire proof as possible and that all parts are readily accessible affording easy operation. All machinery of heavy type can be easily handled by crane so that repairs may be easily accomplished. In this connection a spare transformer has been stored in the plant which can be quickly substituted for a disabled transformer, allowing continuous service.

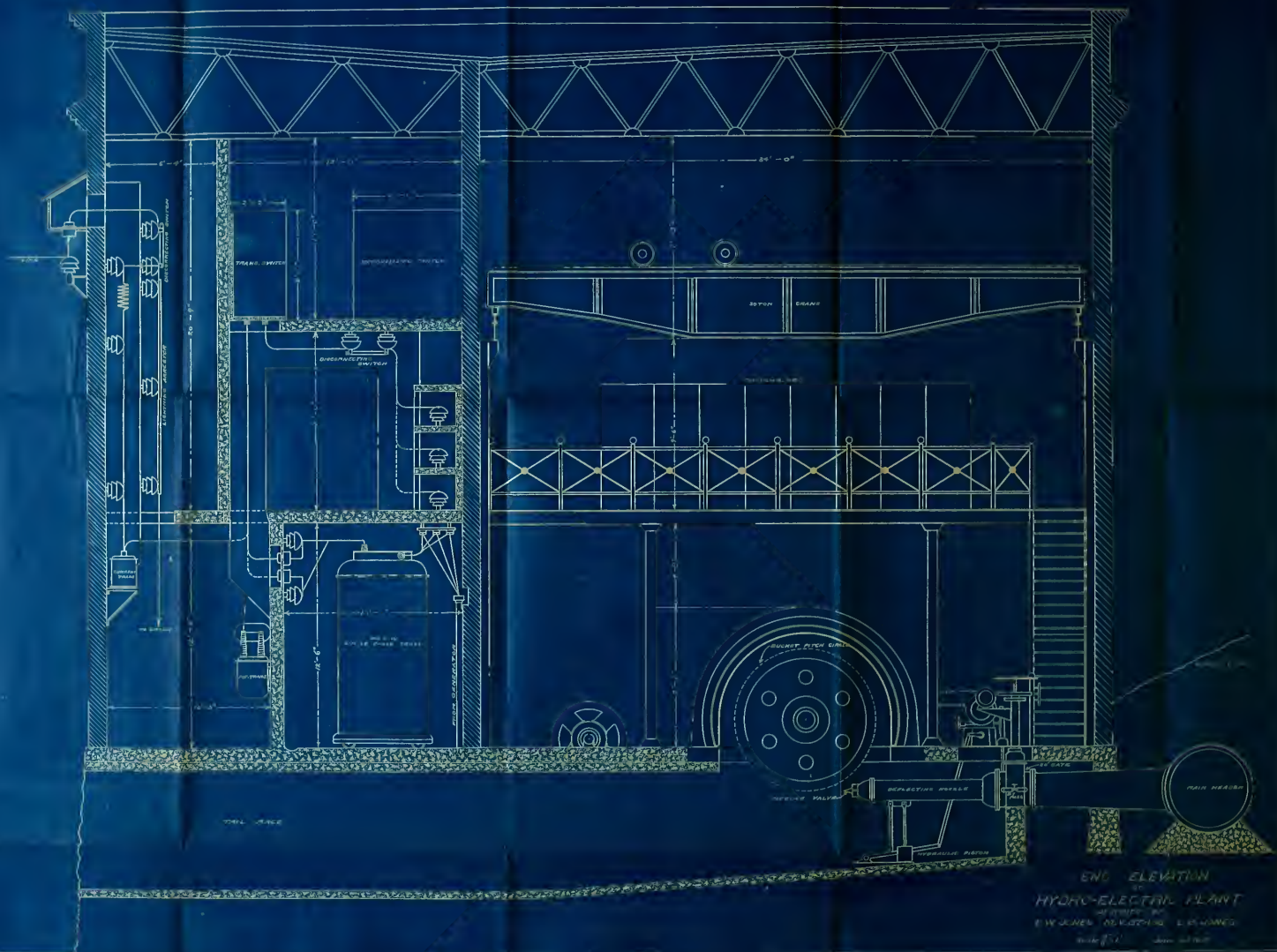
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C PLANT

L. B. JONES

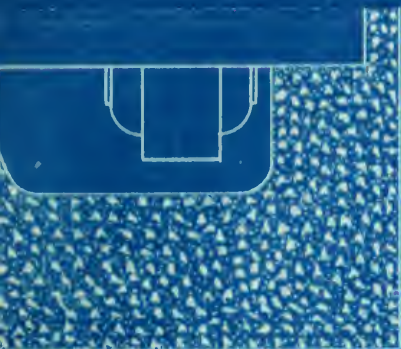
E. 142 1907

Side Elevation
of
Switch House
and
Generator Room



END ELEVATION
OF
HYDRO-ELECTRIC PLANT
DESIGNED BY
E. W. JONES, NEWARK, N. J.
JAN. 1910

Side Elevation
of
Switch House.



SIDE
HYDRO-ELE
DESIGN
E.W. JONES M.V.

Scale $\frac{3}{8}$ " = 1'

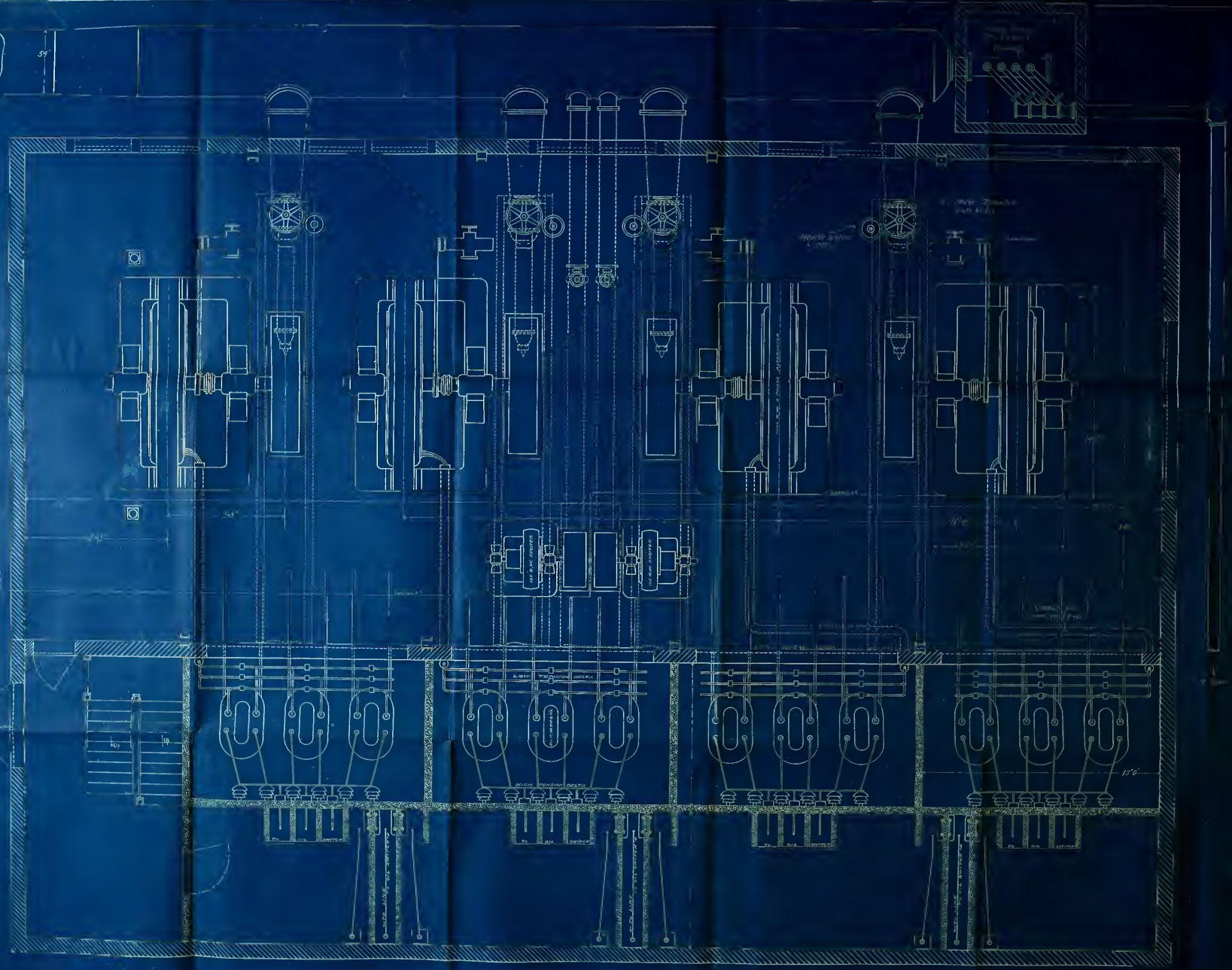


SIDE ELEVATION
HYDRO-ELECTRIC PLANT
ENGINEER: J. B. LEE
ARCHITECT: J. B. LEE
DATE: 1917

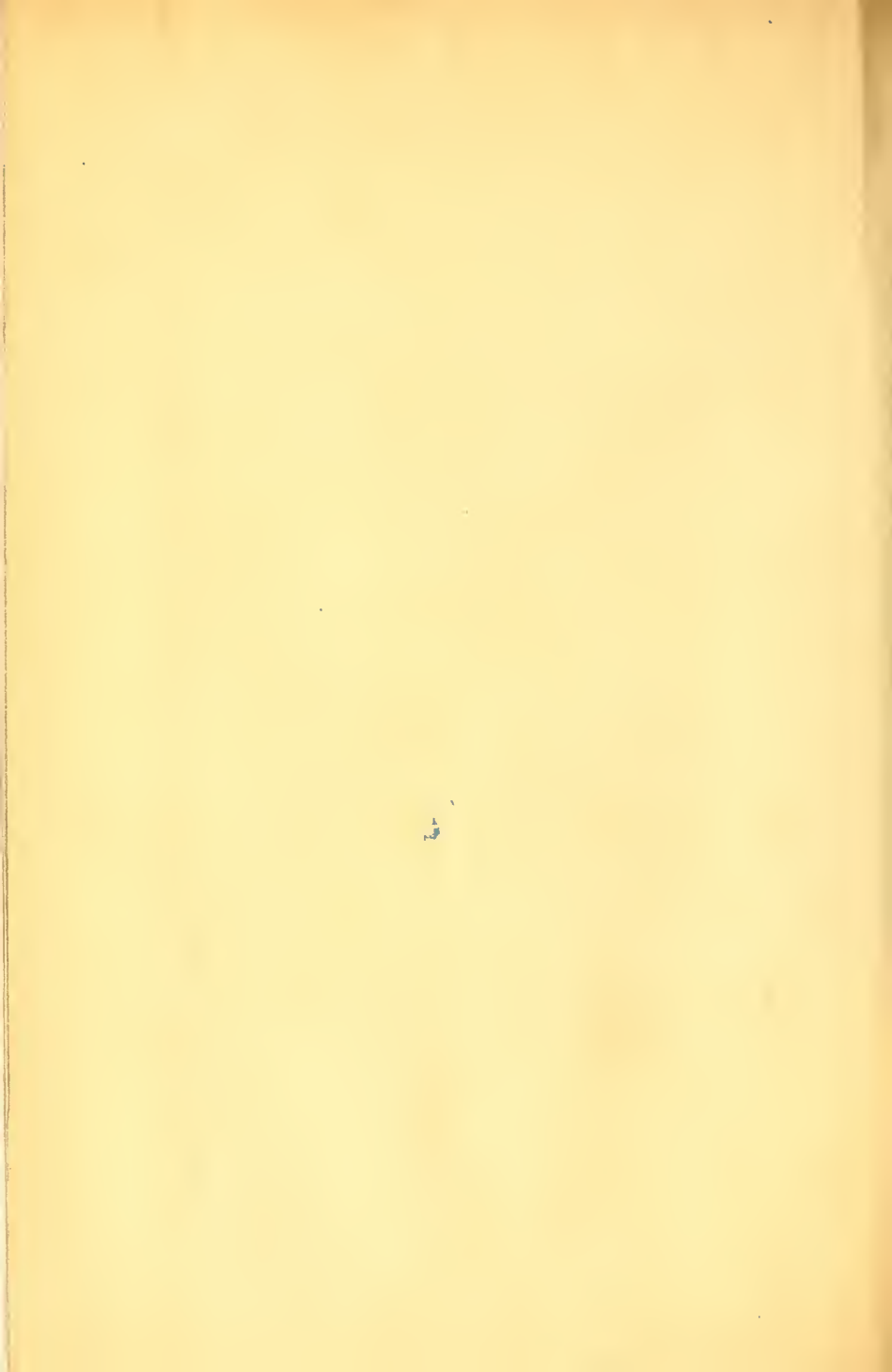
PLAN
OF
HYDRO-ELECTRIC PLANT

DESIGNED BY
E.W. JONES M.V. STAGG L.B. JONES

Scale $\frac{3}{8}'' = 1'$ June 1907



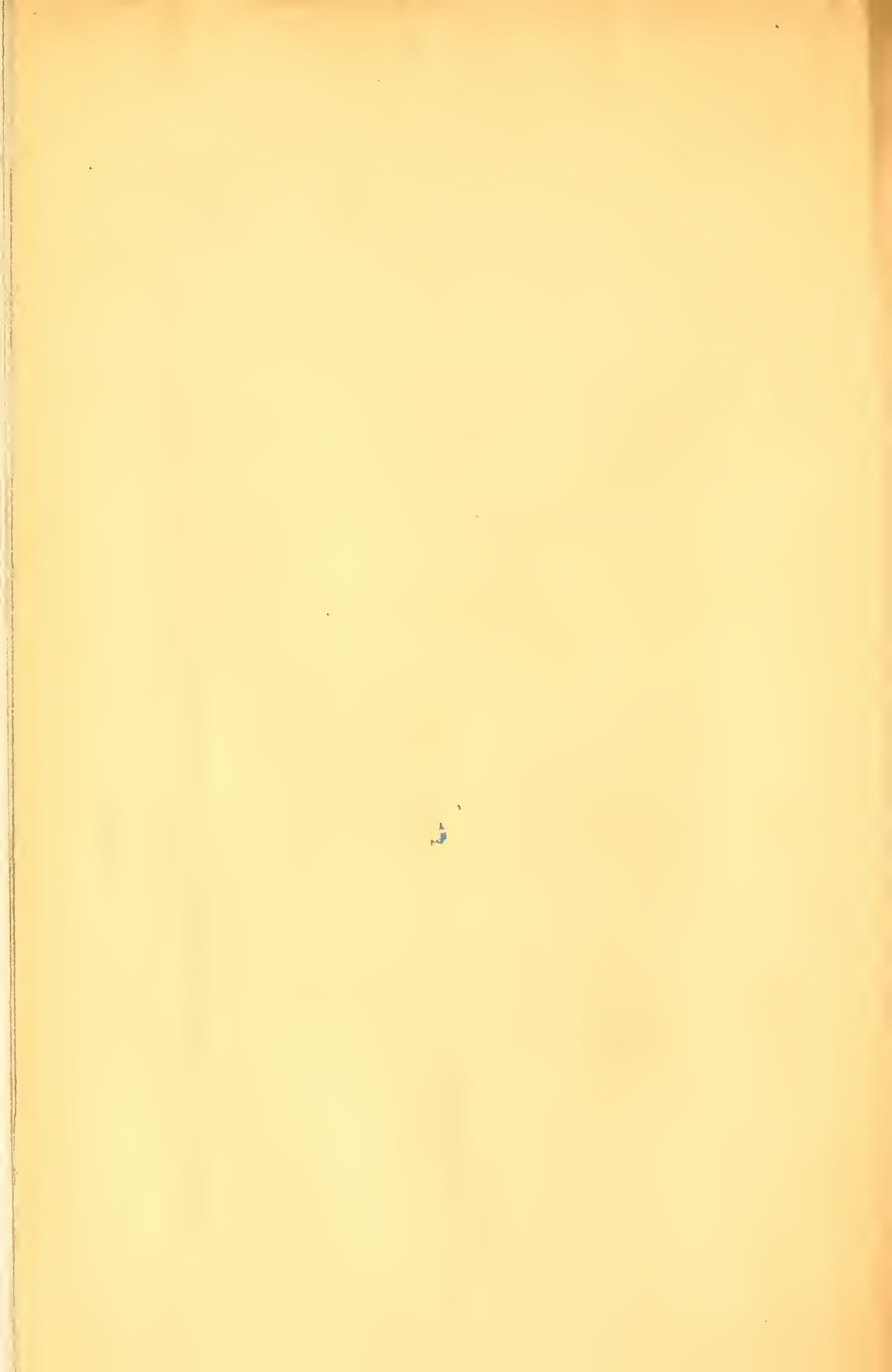
PLAN





PLAN
OF
HYDRO-ELECTRIC
DESIGNED BY
E.W. JONES M.V. STAGG

Scale $\frac{3}{8}'' = 1'$ June 1922



Side Elevation
of
Switch House.

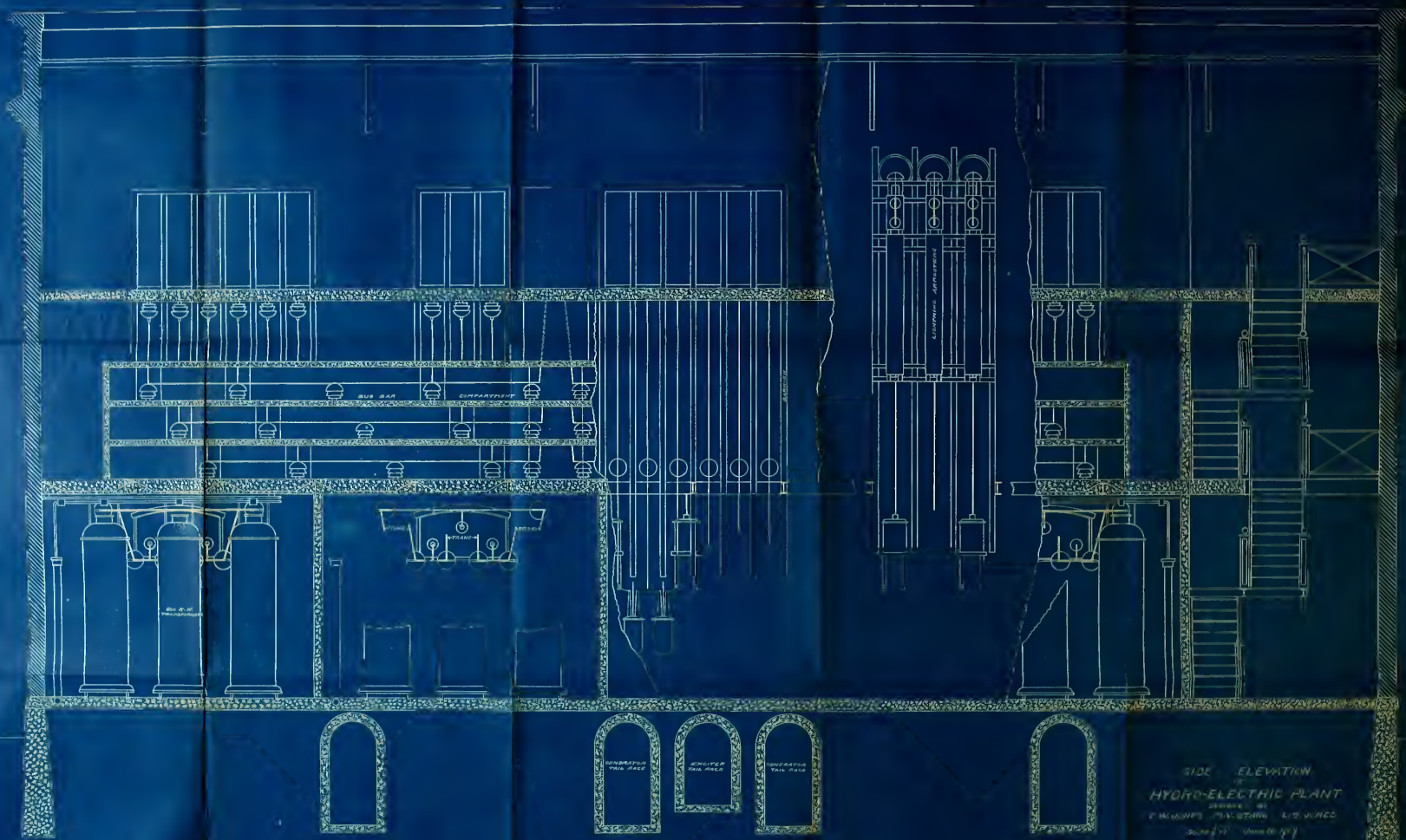


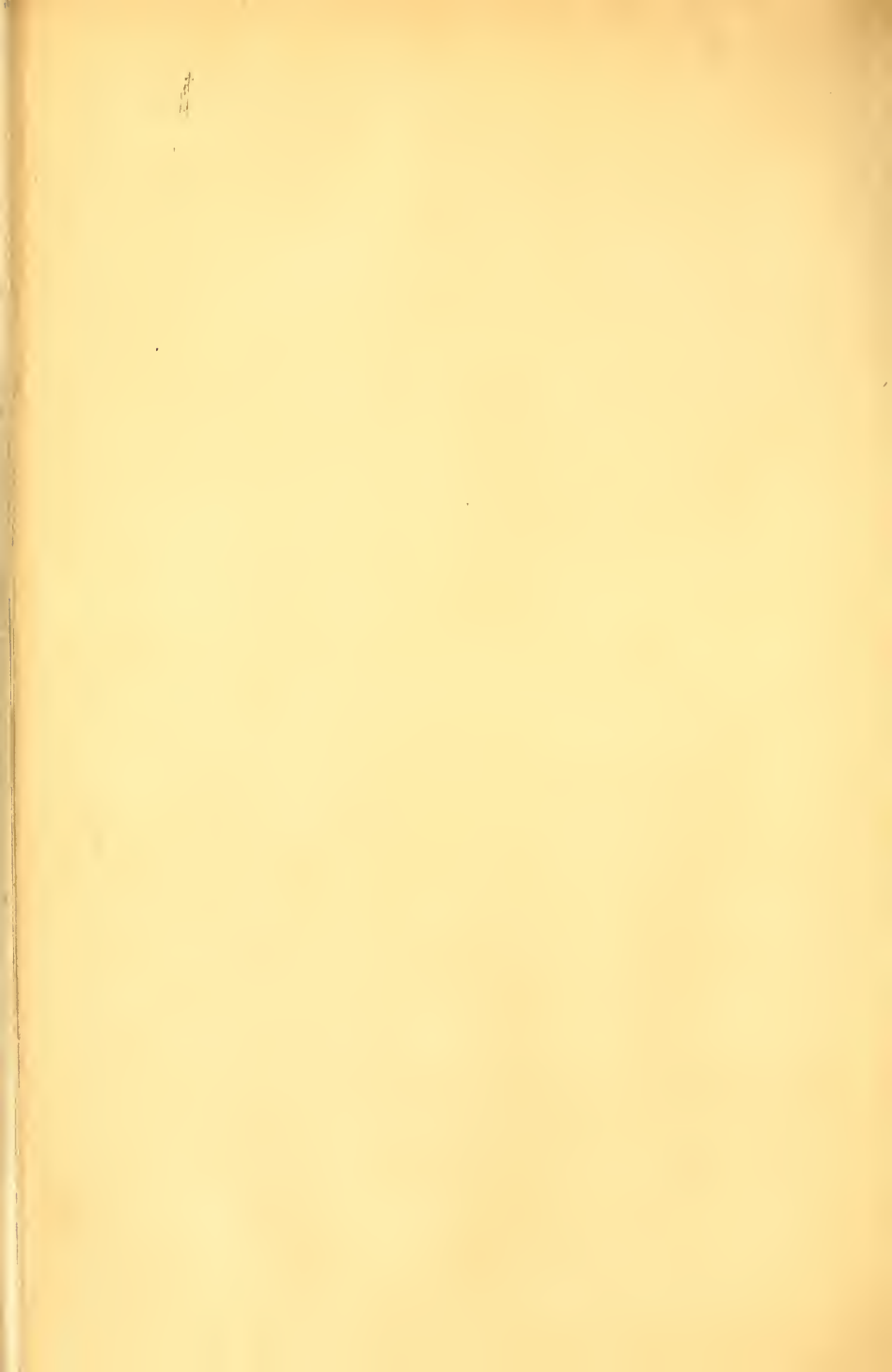
SIDE ELEVATION
OF
HYDRO-ELECTRIC PLANT

DESIGNED BY
E.W. JONES M.V. STAGG L.B.

Scale $\frac{3}{8}'' = 1'$ JUNE 14th 1907

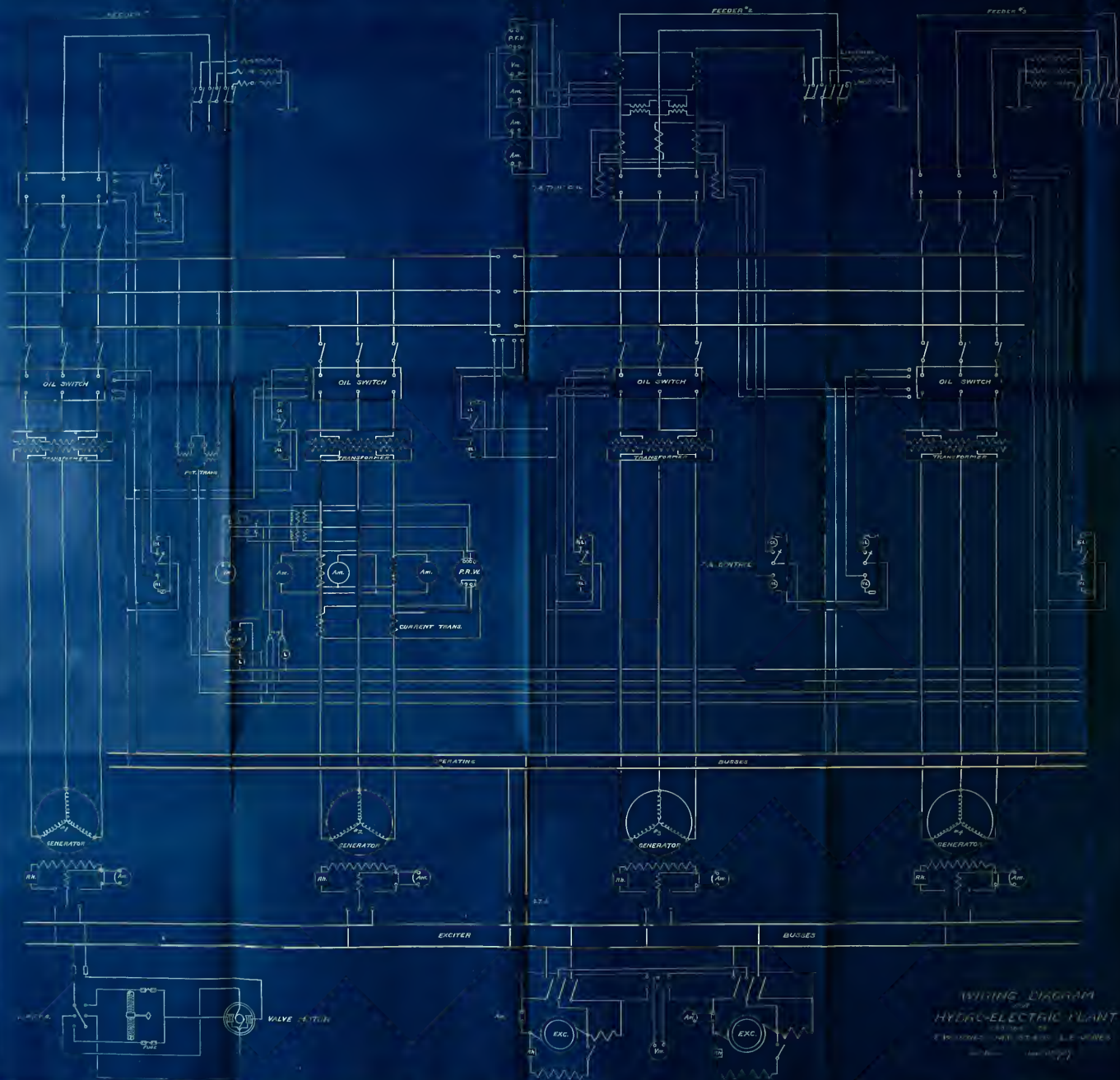






Switch Board.

Wing Diagram



WIRING DIAGRAM
of
HYDRO-ELECTRIC PLANT
DESIGNED BY
E. H. HARRIS, JR., C.E.
NEW YORK, N.Y.

Detail of
Applegate Hydraulic
Governor.

URNS

HAFT

DETAIL
OF
LIMBARD-REPLOGLE GENERATOR
FOR
HYDRO-ELECTRIC PLANT
DESIGNED BY
ENGINEERS M.V. S. H. & B. W. W. W.
SOUTH AFRICA

WIND SPEED INDICATOR - 10000
10000

